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13. ABSTRACT (Maximum 200 words)

Research efforts have centered in the areas of parallel and distributed computing, network architecture, combinatorial algorithms, and complexity theory. Significant progress has been made on the development of efficient sorting circuits, network management protocols for high speed nertworks, distributed graph algorithms and data structured, improved algorithms for packet routing and sorting in parallel machines, algorithms for reconfiguring networks around faults, improved approximation algorithms for a variety of NP-hard optimization problems, VLSI design, and algorithms for combinatorial problems such as multicommodity flow.

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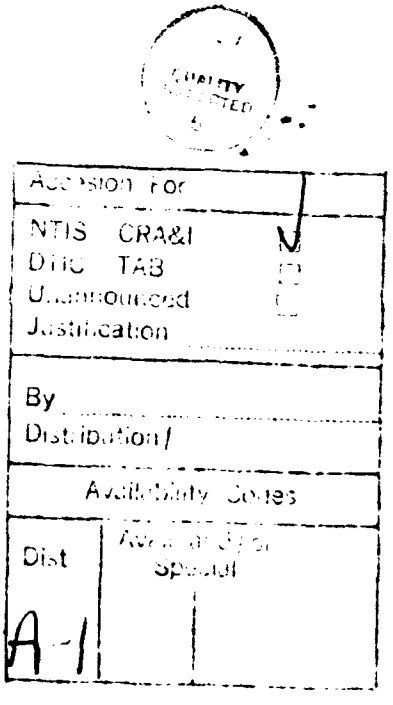

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Summary

Our research efforts have centered in the areas of parallel and distributed computing, network architecture, combinatorial algorithms, and complexity theory. Significant progress has been made on the development of efficient sorting circuits, network management protocols for high speed networks, distributed graph algorithms and data structures, improved algorithms for packet routing and sorting in parallel machines, algorithms for reconfiguring networks around faults, improved approximation algorithms for a variety of NP-hard optimization problems, VLSI design, and algorithms for combinatorial problems such as multicommodity flow.

Particular highlights include:

- the work of Leighton and Maggs on the computational power and fault-tolerance of randomly-wired networks,
- the discovery of the first optimal algorithms for routing on a nonblocking network by Arora, Leighton, and Maggs,
- the work of Leighton and Plaxton on the construction of a simple $c \log N$-depth circuit (where $c < 7.5$) that sorts a random permutation with very high probability,
- the work of Leighton, Tardos, et.al. on the discovery of dramatically faster approximation algorithms for multicommodity flow problems, and
- the work of Awerbuch et al. on the development of a wide array of protocols for distributed networks.

Copies of papers describing these highlights are enclosed with the report.

We have enclosed a complete list of publications and theses supported by the contract with this report. Copies of the papers and/or detailed information about the results they contain will be furnished upon request.

Papers Supported by AFOSR-89-0271
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1. Y. Afek, B. Awerbuch and H. Moriel, "Overhead of resetting a communication protocol is independent of the size of the network", Technical Memo MIT/LCS/TM-377, MIT, May.1989.

2. Y. Afek, B. Awerbuch, S. Plotkin, and M. Saks, "Local Management of a Global Resource in a Communication Network", Accepted for publication to *JACM*, subject to revisions.

3. A. Aggarwal, M. Hansen, F.T. Leighton, "Solving Query-Retrieval Problems by Compacting Voronoi Diagrams," Proc. 22nd ACM Symp. on Theory of Computing, May 1990, pp.331-340.

4. A. Aggarwal, F.T. Leighton, "A Tight Lower Bound for a Train Reversal Problem," Info. Proc. Letters, Vol. 35 No. 6, 1990, pp. 301-304.

5. A. Aggarwal, F.T. Leighton, K. Palem, "Area-Time Optimal Circuits for Iterated Addition in VLSI," IEEE Trans. on computers, to appear.

6. B. Aiello and T. Leighton, "Coding Theory, Hypercube Embeddings, and Fault Tolerance," *Proc. 3rd ACM Symp. on Parallel Algorithms and Architectures*, pp. 125-136, July 1991.

7. B. Aiello, F.T. Leighton, B. Maggs, M. Newman, "Fast Algorithms for Bit-Serial Routing on a Hypercube," Proc. 2nd ACM Symp. on Parallel Algorithms and Architectures, July 1990, pp. 55-64. (Also appears in *Math Systems Theory*, Vol. 24, pp. 253-271, 1991.)

8. M. Aigner, D. Duffus, and D. Kleitman, "Partitioning a power set into union-free classes," *Discrete Mathematics*, Vol. 88, pp. 113-119, North-Holland (1991).

9. B. Aronov, P. Erdős, W. Goddard, D. J. Kleitman, M. Klugerman, J. Pach, and L. J. Schulman, "Crossing Families." In, *Proceedings 7th Symposium on Computational Geometry*, June, 1991.

10. S. Arora, F.T. Leighton, B. Maggs, "On-line Algorithms for Path Selection in a Nonblocking Network," Proc. 22nd ACM Symp. on Theory of Computing, May 1990, pp. 149-158.

11. B. Awerbuch, "Distributed shortest paths algorithms ", *21st ACM Symposium on Theory of Computing, May 1989, Seattle, Washington*. pp. 230-240

12. B. Awerbuch, "On the effects of feedback in dynamic network protocols". Special issue of the *Journal of Algorithms*, Vol 11, 1990.

13. B. Awerbuch, "Loop-Free Routing", Proceedings of 1990 ACM Symposium on Communication Architectures and Protocols (SIGCOM), Philadelphia, Pennsylvania, pp. 177-187.

14. B. Awerbuch, A. Baratz and D. Peleg, "Cost-Sensitive Analysis of Communication Protocols", 1990 Symposium on Principles of Distributed Computing (PODC), pp. 189-204.

15. B. Awerbuch, A. Bar-Noy and M. Gopal, "Approximate Distributed shortest paths algorithms", Proceedings of the 1991 IEEE Infocom 91, pp. 1206-1213. (Also to appear in *IEEE Trans. on Communication.*)

16. B. Awerbuch, A. Bar-Noy, N. Linial and D. Peleg, "Compact Distributed Data Structures for Adaptive Network Routing", *21st ACM Symp. on Theory of Computing*, May 1989.

17. B. Awerbuch, A. Bar-Noy, N. Linial and D. Peleg, "Improved Routing Strategies with Succinct Tables", Special issue of the *Journal of Algorithms*, Vol 11, 1990.

18. B. Awerbuch, B. Berger, L. Cowen and D. Peleg "Low Diameter Graph Decomposition is in NC", Third Scandinavian Workshop on Algorithm Theory (SWAT), July 1992, Helsinki, Finland (to appear).

19. B. Awerbuch, B. Berger, L. Cowen and D. Peleg "Fast Distributed Network Decompositions", 1992 Symposium on Principles of Distributed Computing (PODC), August 1992, Vancouver, British Columbia (to appear).

20. B. Awerbuch, I. Cidon, I. Gopal, M. Kaplan and S. Kutten, "Distributed Control for PARIS", 1990 Symposium on Principles of Distributed Computing (PODC), pp. 145-160.

21. B. Awerbuch, I. Cidon and S. Kutten, "Optimal Maintenance of Replicated Information", 31'th IEEE Symposium on Found. of Computer Science, October 1990, St. Louis, Missouri, pp. 492-502.

22. B. Awerbuch, I. Cidon, S. Kutten, Y. Mansour and D. Peleg, "Broadcast with Partial Knowledge", Proceedings of the 1991 Symposium on Principles of Distributed Computing (PODC), pp. 153-163.

23. B. Awerbuch, A. Goldberg, M. Luby and S. Plotkin, "Network Decomposition and Locality in Distributed Computation", 30'th IEEE Symposium on Found. of Computer Science, October 1989, Durham, North Carolina, pp. 364-369.

24. B. Awerbuch, O. Goldreich and A. Herzberg, "A quantitative approach to dynamic networks", 1990 Symposium on Principles of Distributed Computing (PODC), pp. 177-188.

25. B. Awerbuch, O. Goldreich, D. Peleg and R. Vainish, "A Tradeoff Between Information and Communication in Broadcast Protocols". *Journal of the ACM*, Vol. 37, No. 2, April 1990, pp. 238-256.

26. B. Awerbuch, S. Kutten and D. Peleg, "On Buffer-Economical Store-and-Forward Deadlock Prevention", Proceedings of the 1991 IEEE Infocom 91, pp. 0410-0414. (Also to appear in *IEEE Trans. on Communication*.)

27. B. Awerbuch, S. Kutten and D. Peleg, "Efficient Deadlock-free Routing", Proceedings of the 1991 Symposium on Principles of Distributed Computing (PODC), pp. 177-188.

28. B. Awerbuch, S. Kutten and D. Peleg, "Competitive Distributed Job Scheduling", 24'th ACM Symposium on Theory of Computing, May 1992, Vancouver, British Columbia, to appear.

29. B. Awerbuch, Y. Mansour, "Topology Update in Dynamic Networks". Submitted for publication to *IEEE Trans. on Computers*.

30. B. Awerbuch, Y. Mansour and N. Shavit, "Polynomial End-To-End Communication", 30'th IEEE Symposium on Found. of Computer Science, October 1989, Durham, North Carolina, pp. 358-363.

31. B. Awerbuch, B. Patt and G. Varghese, "Self-Stabilization by Local Checking and Correction", 32'th IEEE Symposium on Found. of Computer Science, October 1991, San Juan, pp. 268-277.

32. B. Awerbuch, B. Patt, D. Peleg and M. Saks, "Adapting to Asynchronous Dynamic Networks with Polylogarithmic Overhead", 24'th ACM Symposium on Theory of Computing, May 1992, Vancouver, British Columbia, to appear.

33. B. Awerbuch and D. Peleg, "Online tracking of mobile users". Submitted for publication to *JACM*.

34. B. Awerbuch and D. Peleg, "Routing with Polynomial Communication-Space Tradeoff". Accepted for publication to the *SIAM Journal on Discrete Math*.

35. B. Awerbuch and D. Peleg, "Efficient Distributed Construction of Sparse Covers". Technical report CS90-17, Weizmann Institute, July 1990.

36. B. Awerbuch, D. Peleg, "Network Synchronization with poly-logarithmic overhead", 31'th IEEE Symposium on Found. of Computer Science, October 1990, St. Louis, Missouri, pp. 514-522.

37. B. Awerbuch, D. Peleg, "Sparse Partitions", 31st IEEE Symposium on Found. of Computer Science, October 1990, St. Louis, Missouri, pp. 503-513.

38. B. Awerbuch, and D. Peleg "Concurrent Online Tracking of Mobile Users", Proceedings of 1991 ACM Symposium on Communication Architectures and Protocols (SIGCOM), Zurich, Switzerland, September 1991, pp. 221-233.

39. B. Awerbuch and M. Saks, "Dining Philosophers algorithms with polynomial response time," 31st IEEE Symposium on Found. of Computer Science, October 1990, St. Louis, Missouri, pp. 65-75.

40. B. Awerbuch and L. Schulman, "The Maintenance of Common Data in a Distributed System", 32'th IEEE Symposium on Found. of Computer Science, October 1991, San Juan pp. 505-514.

41. B. Awerbuch and G. Varghese, "Distributed Program Checking: a Paradigm for Building Self-stabilizing Distributed Protocols", 32'th IEEE Symposium on Found. of Computer Science, October 1991, San Juan, pp. 258-267.

42. Francisco Barahona and Éva Tardos, "Note on Weintraub's minimum cost flow algorithm," SIAM Journal on Computing. 18, 1989, 579-583.

43. J. Bentley, F.T. Leighton, M. Lepley, D. Stanat, M. Steele, "A Randomized Data Structure for Ordered Sets," Advances in Computing Research: Randomness and Computation," JAI Press, 1989, pp. 413–428.

44. B. Berger, J. Rompel, P. Shor, "Efficient NC Algorithms for Set cover with Applications to Learning and Geometry," to appear, 30th Annual IEEE Symposium on Foundations of Computer Science, 1989.

45. B. Berger, M. Brady, D. Brown, F.T. Leighton, Nearly Optimal Algorithms and Bounds for Multilayer Channel Routing," JACM, to appear.

46. F. Berman, D. Johnson, F.T. Leighton, P. Shor, L. Snyder, "Generalized Planar Matching," J. Algorithms, Vol. 11 No. 2, 1990, pp. 153–184.

47. D. Bhatia, F.T. Leighton, F. Makedon, "Efficient Reconfiguration of WSI Arrays," Proc. 1st ACM/IEEE Int. Conf. on system Integration, April 1990, pp. 46–47.

48. S. Bhatt, F. Chung, F.T. Leighton, A. Rosenberg, "Universal Graphs for Bounded Degree Trees and Planar Graphs," SIAM J. Discrete Math., Vol. 2 No. 2, May 1989, pp. 145–155.

49. S. Bhatt, F. Chung, J. Hong, F.T. Leighton, A. Rosenberg, "Optimal Simulations by Butterfly Networks," JACM, to appear.

50. S. Bhatt, F. Chung, F.T. Leighton, A. Rosenberg, "Efficient Embeddings of Trees in Hypercubes," SIAM J. Computing, Vol. 21, No. 1, Feb. 1992, pp. 151–162.

51. S. Bhatt, D. Greenberg, F.T. Leighton, P. Liu, "Lower-bounds for On-Line Tree Embeddings," Proc. 2nd Annual ACM/SIAM Symp. on discrete Algorithms, Jan. 1991, pp. 344-350.

52. Daniel Bienstock, Michel X. Goemans, David Simchi-Levi, and David P. Williamson, "A note on the prize collecting traveling salesman problem," 1990. To appear in *Mathematical Programming*.

53. R. Boppana, M. Sipser, "The Complexity of Finite Functions," Handbook of Theoretical Computer Science, 1990, 759-800.

54. T. Bui, C. Heigham, C. Jones, F.T. Leighton, "Improving the Performance of the Kernighan-Lin and Simulated Annealing Graph Bisection Algorithms, Proc. 1989 Design Automation Conference, pp. 775–778, June 1989.

55. B. Chor, M. Merritt, D.B. Shmoys, "Simple constant-Time Consensus Protocols in Realistic Fault Models," to appear, JACM, 1989. An earlier version of this appeared in the 4th Symposium on Principles of Distributed Computing.

56. D.K. Du, Daniel Kleitman, "Diameter and Radius in the Manhattan Metric," Discrete & Computational Geometry, Vol. 5, 1990, pp. 351–356.

57. M. Formann, T. Hagerup, J. Haralambides, F.T. Leighton, A. Simvonis, E. Welzl, G. Woeginger, "Drawing Graphs in the Plane with High Resolution," Proc. 31st IEEE Symp. on Theory of Computing, October, 1990, pp. 86-95.

58. L. Fortnow, *On Complexity Theory*, PhD thesis, 1989.

59. Andras Frank, Takao Nishizeki, Nobuji Saito, Hitoshi Suzuki and Éva Tardos, "Algorithms for routing around a rectangle," Discrete Applied Mathematics, accepted for publication 1991.

60. Z. Furedi, Jeff Kahn, D. Kleitman, "Sphere Coverings of the Hypercube with Incomparable Centers," Discrete Mathematics Vol. 83, 1990, pp. 129–134.

61. Z. Furedi and D. Kleitman, "On Zero Trees," submitted to *J. Graph Theory* (1990).

62. Z. Furedi, D. Kleitman, "The Prison Yard Problem," Combinatorica, 1990.

63. Wayne Goddard and D. Kleitman, "An Upper Bound for the Ramsey Numbers $r(K_3, G)$," submitted to *Discrete Mathematics*. Presented at British Combinatorics (1991).

64. Wayne Goddard and D. Kleitman, "Convergence of a Transformation on a Weight Graph," *Congressus Numeratium*, Vol. 82, Dec. 1991, pp. 179–185.

65. Michel X. Goemans, "The Steiner tree polytope and related polyhedra," 1991. Submitted to *Mathematical Programming*.

66. Michel X. Goemans, "Arborescence polytopes for series-parallel graphs," 1991. Submitted to *Discrete Applied Mathematics*.

67. Michel X. Goemans, "Polyhedral description of trees and arborescences," to appear, Proceedings of the 2nd Integer Programming and Combinatorial Optimization conference," 1992.

68. Michel X. Goemans and Young-Soo Myung, "A catalog of Steiner tree formulations," 1991. Submitted to *Networks*.

69. Michel X. Goemans and David P. Williamson, "A general approximation technique for constrained forest problems." In, Proceedings of the 3rd ACM-SIAM Symposium on Discrete Algorithms, January, 1992, pp. 307–316.

70. Andrew V. Goldberg, Serge A. Plotkin, David B. Shmoys and Éva Tardos. "Fast Parallel Algorithms for Bipartite Matching and Related Problems." SIAM Journal on Computing, 1992, 21/1 140-150.

71. A. Goldberg, S. Plotkin, D. Shmoys, É. Tardos, "Interior-Point Methods in Parallel Computation," 30th Annual Symposium on Foundations of Computer Science, Comp. Soc. of the IEEE, 1989.

72. Andrew Goldberg, Serge Plotkin and É. Tardos, "Combinatorial algorithms for the generalized circulation problem." Mathematics of Operations Research. 1991, 16/2 351-381.

73. Andrew V. Goldberg, Éva Tardos and Robert E. Tarjan, "Network flow algorithms," in, Flows, Paths and VLSI-Layout, Springer Verlag, 1990, 101-164.

74. Jerrold R. Griggs, Daniel Kleitman, "Minimum Cutsets for an Element of a Boolean Latice," IMA Preprint Series #499, February 1989.

75. J.R. Griggs and D. Kleitman, "Independence and the Havel-Hakimi Residue," Annals of Discrete Mathematics, in press (1992).

76. Jerrold R. Griggs, D. Kleitman, Aditya Shastri, "Spanning Trees with Many Leaves in Cubic Graphs," Journal of Graph Theory, Vol. 13, No. 6, pp. 669-695, 1989.

77. M. Grigni, D. Peleg, "Tight Bounds on Minimum Broadcast Networks," to appear in the SIAM Journal on Discrete Mathematics.

78. M. Grigni, M. Sipser, "Monotone Complexity," to appear on the Proceedings of the 1990 Durham London Mathematical Society Conference on Circuit Complexity.

79. M. Grigni, M. Sipser, "Monotone Separation of Logspace from NC1," to appear in the 1991 conference on Structure in Complexity Theory.

80. P. Hajnal, "An $\Omega(N^{\frac{4}{3}})$ Lower Bound on the Randomized Decision Tree Complexity of Graph Properties, to appear, Combinatorica, 1989.

81. P. Hajnal, E. Szemerédi, "Brooks Coloring in Parallel," to appear, SIAM J. Disc. Math. 1989.

82. P. Hajnal, "On Coloring Generalized Shift Graphs," manuscript, May 1989

83. P. Hajnal, M. Szegedy, "On Packing Bipartite Graphs," manuscript, June, 1989.

84. L. Hall, D. Shmoys, "Approximation Schemes for Constrained Scheduling Problems," 30th Ann. Symp. on Found. of Computer Science, Comp. Soc. of the IEEE, 1989.

85. L. Hall, D. Shmoys, "Jackson's Rule: Making a Good Heuristic Better," Mathematics of OR, to appear, December 1989.

86. J. Hastad, F.T. Leighton, M. Newman, "Fast Computation Using Faulty Hypercubes," Proc. 21st Symp. on Theory of Computing, May 1989, pp. 251-263.

87. D. Hochbaum, D. Shmoys, "A Polynomial Approximation Scheme for Scheduling Uniform Parallel Machines," accepted for publication, SIAM J. of Computing.

88. N. Kahale, "New Modular Properties of Bell Numbers," Journal of Combinatorial Theory Series A, 58(1), 147-152 (1991).

89. N. Kahale, "Better Expansion for Ramanujan Graphs," FOCS91, pp. 398–404.

90. Nabil Kahale, "Tight bound on the expansion of Ramanujan Graphs." Manuscript, 1991.

91. Nabil Kahale and Tom Leighton, "Greedy Routing on Arrays." Manuscript, 1991.

92. C. Kaklamanis, A. Karlin, F.T. Leighton, V. Milenkovic, P.Raghavan, S. Rao, C. Thomborson, T. Tsantilas, "Asymptotically Tight Bounds for Computing with Faulty Arrays of Processors," *Proc. 31st IEEE Symp. on Theory of Computing*, October, 1990, pp. 285–296.

93. G. Kindervater, J. Lenstra, D. Shmoys, "The Parallel Complexity of TSP Heuristics," *J. Algorithms*, 10:249–70, 1989.

94. Maria K. Klawe, D. Kleitman, "An Almost Linear Time Algorithm for Generalized Matrix Searching," *SIAM Journal of Discrete Mathematics*, Vol. 3, No. 1, pp. 81–97, February 1990.

95. M. Klawe, F.T. Leighton, "A Tight Lower Bound on the Size of Planar Permutation Layouts," *Proc. SIGAL Int. Symp. on Algorithms*, Aug. 1990, pp. 281–287. (Also to appear in *SIAM J. Disc. Math.*)

96. P. Klein, "Parallelism, Preprocessing and Reachability," Contemporary Math., 89:129–43, 1989.

97. P. Klein, J. Reif, "An Efficient Parallel Algorithm for Planarity," accepted for publication in *JCSS*, 1989.

98. P. Klein, C. Stein, "A Parallel Algorithm for Eliminating Cycles in Undirected Graphs," Center for Research in Computing Technology Technical Report TR-01-89, Harvard University, March 1989. Submitted to Info. Proc. Lett.

99. D. Kleitman, "Extremal Problems on Hypergraphs," submitted to *Annals of Discrete Math* (11/2.90) for volume for Japan Conference.

100. D. Kleitman, "Collections of Sets without Unions and Intersections," Reprint from Combinatorial Mathematics Proceedings of the Third International Conference," Vol. 555 of the Annals of the N.Y. Academy of Sciences, May 28, 1989.

101. D. Kleitman, "Divisors With Unit-Congruent Ratios," SIAM Journal of Discrete Mathematics, Vol. 2, No. 3, Aug. 1989, pp. 344–349.

102. D. Kleitman, Paul Leinke, "An Addition Theorem on the Integers Modulo N," *Journal of Number Theory*, Vol. 31, No. 3, March 1989.

103. D. Kleitman, G.W. Peck,and A. Shastri, "Bandwidth of Theta Graphs with Short Paths," accepted for publication in *Discrete Mathematics*, July 13, 1990.

104. D. Kleitman, Douglas B. West, "Spanning Trees with Many Leaves," *SIAM Journal on Discrete Mathematics*, 1989.

105. M. Klugerman and C.G. Plaxton, "Small-Depth Counting Networks," to appear, *Proceedings of the 24th Annual Symposium on Theory of Computing*, May 1992

106. R. Koch, *An Analysis of the Performance of Interconnection Networks for Multiprocessor Systems*, PhD thesis, June 1989.

107. R. Koch, T. Leighton, B. Maggs, S. Rao, and A. Rosenberg, "Work-Preserving Emulations of Fixed-Connection Networks," *Proc. 21st ACM Symp. on Theory of Computing*, pp. 227–240, May, 1989.

108. E. Lawler, J. Lenstra, A. Rinnooy Kan, D. Shmoys, "Sequencing and Scheduling: Algorithms and Complexity," In S.Graves, A. Rinnooy Kan and P. Zipkin (eds.), The Handbooks of Operations Research and Management Science, Vol. IV Product Planning and Inventory, North-Holland, 1989, to appear

109. F.T. Leighton, "A $2x - 1$ Lower Bound for 2-Layer Knock-Knee Channel Routing," *SIAM J. Discrete Math.*, to appear.

110. F.T. Leighton, "Average Case Analysis of Greedy Routing Algorithms on Arrays," Proc. 2nd ACM Symp. on Parallel algorithms and Architectures, July 1990, pp. 2–10.

111. F.T. Leighton, *Introduction to Parallel Algorithms and Architectures: Arrays - Trees - Hypercubes*, Morgan Kaufmann Publishers, San Mateo, CA, August, 1991

112. F.T. Leighton, D. Lisinski, B. Maggs, "Empirical Analysis of Randomly-Wired Multistage Networks," Proc. IEEE Int. Conf. on Computer Design, September 1990, pp. 380–385.

113. F.T. Leighton, B. Maggs, "Expanders Might Be Practical: Fast Algorithms for Routing Around Faults on Multibutterflies," Proc. 30th IEEE Conf. on Found. of Comp. Sci., Oct. 1989, pp. 384–389.

114. T. Leighton and B. Maggs, "Fast Algorithms for Routing Around Faults in Multibutterflies and Randomly-wired Splitter Networks," *IEEE Trans. on Computers*, to appear (1992).

115. T. Leighton, B. Maggs, A. Ranade, and S. Rao, "Randomized Algorithms for Routing and Sorting in Fixed-Connection Networks," *J. Algorithms*, to appear (1992).

116. T. Leighton, B. Maggs, and S. Rao, "Packet Routing and Job-Shop Scheduling in O(Dilation + Congestion) Steps," *Combinatorica*, to appear, 1992.

117. T. Leighton, F. Makedon, S. Plotkin, C. Stein, E. Tardos, and S. Tragoudas, "Fast Approximation Algorithms for Multicommodity Flow Problems," *23rd Annual ACM Symp. on Theory of Computing*, pp. 101-111, May, 1991.

118. F.T. Leighton, F. Makedon, I. Tollis, "A $(2N - 2)$-Step Algorithm for Routing in an $N \times N$ Array with Constant Size Queues," Proc. 1st ACM Symp. on Parallel Algorithms and Architectures," pp. 328–335, June 1989. (Also to appear in *Algorithmica*.)

119. F.T. Leighton, F. Makedon, S. Tragoudas, "Approximation Algorithms for VLSI Partition Problems," Proc. IEEE Int. Symp. on circuitsand Systems, May 1990, pp. 2865–2869.

120. F.T. Leighton, M.J. Newman, A.G. Ranade, and E.J. Schwabe, "Dynamic Tree Embeddings in Butterflies and Hypercubes" In Proceedings of the 1st ACM SPAA, pages 224-234, 1989. (also to appear in SIAM Journal on Computing, 1992.)

121. F.T. Leighton, G. Plaxton, "A (Fairly) Simple Circuit That (Usually) Sorts," Proc. 31st IEEE Symp. on Theory of Computing, October 1990, pp. 264–274

122. F. T. Leighton and E.J. Schwabe "Efficient Algorithms for Dynamic Allocation of Distributed Memory" In Proceedings of the 32nd IEEE FOCS, pages 470-479, 1991.

123. F.T. Leighton, P. Shor, "Tight Bounds for Minimax Grid Matching, with Applications to the Average Case Analysis of Algorithms," Combinatorica, Vol. 9 No. 2, 1989, pp. 161–187.

124. J.K. Lenstra, D.B. Shmoys and E. Tardos, "Approximation Algorithms for Scheduling Unrelated Parallel Machines." Mathematical Programming A, 1990, 46, 259-272.

125. D. Lisinski, *Evaluation of Cut-Through Routing in Multibutterfly Networks*, BSE Thesis, June 1990.

126. M. Newman, *Randomness and Robustness in Hypercube Computation*, PhD thesis, July 1989.

127. C. H. Norton, S. Plotkin and É. Tardos, "Using Separation Algorithms in Fixed Dimension." Journal of Algorithms. 13 (SODA'90 special issue) 1992, 79-98. Preliminary version has appeared in the Proceedings of the ACM-SIAM Symposium on Discrete Algorithms (1990) 377-387.

128. Serge Plotkin and Éva Tardos, "Improved dual network simplex." In, Proceedings of the ACM-SIAM Symposium on Discrete Algorithms, 1990, 367-376.

129. Chris Potts, David B. Shmoys, and David P. Williamson, "Permutation vs. non-permutation flow shop schedules," in ORL, 10, 281–284 (1991).

130. S. Rao, *Finding Small Balanced Edge Cuts: Theory and Applications*, PhD thesis, August 1989.

131. J. Rompel, *Techniques for Computing with Low-Independence Randomness*, PhD thesis, Sept. 1990.

132. E.J. Schwabe, "Normal Hypercube Algorithms Can Be Simulated on a Butterfly With Only Constant Slowdown," submitted for publication, 1989.

133. E.J. Schwabe, "On the Computational Equivalence of Hypercube-Derived Networks." In, Proceedings of the 2nd ACM SPAA, pages 388-397, 1990.

134. E.J. Schwabe "Efficient Embeddings and Simulations for Hypercubic Networks" PhD Thesis, Massachusetts Institute of Technology, 1991.

135. E.J. Schwabe "A Benes-like Theorem for the Shuffle-Exchange Graph" To appear in IEEE Transactions on Computers, 1992.

136. D.B. Shmoys and Éva Tardos, *Computational Complexity*, Chapter 31. North-Holland Publishing Co., 1989, to appear.

137. David B. Shmoys, Joel Wein, and David P. Williamson, "Scheduling parallel machines on-line." In, FOCS91, 131–140 (1991).

138. D. Shmoys, D. Williamson, "Analyzing the Held-Karp TSP Bound: A Monotonicity Property with Application," *IPL*, Vol. 35, Sept. 1990, pp. 281–285.

139. M. Sipser, L. Fortnow, "Interactive Proof Systems in Log-Space," submitted to 15th Annual ICALP.

140. E. Tardos. An intersection theorem for supermatroids. Journal of Combinatorial Theory B, 1990, 50/2, 150-159.

141. Joel Wein and David P. Williamson, "On-line scheduling of parallel machines," MITLCS Technical Memo TM-437, Nov., 1990.

142. David P. Williamson, "The non-approximability of shop scheduling." Unpublished manuscript (1991).

143. David P. Williamson, "Analysis of the Held-Karp lower bound for the asymmetric TSP." to appear in Oper. Res. Lett. (1991).

Patents

1. "Switching Networks with Expansive and/or Dispersive Logical Clusters for Message Routing," patent pending (with S. Arora, T. Knight, B. Maggs, and E. Upfal).